

Technology in respiratory medicine

New technological developments mean that respiratory function can be measured by family physicians.



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Respiratory medicine is the subspecialty in medicine which requires the most regular and precise evaluation of physiological function for complete assessment of the patient. The very nature of respiratory physiology requires the availability of a range of technological devices.

Physiological measurements that may be required in a patient undergoing assessment for respiratory disease include pulmonary function tests of varying complexity, measurement of arterial blood gases and pH, exercise testing, various forms of bronchial provocation testing, and the evaluation of sleep. These measurements have been possible for a number of years and require a considerable knowledge of, and investment in, technology.

Lung volume measurements were first made in the 17th century and measurements of respiratory mechanics and breathing function were accomplished in the early 19th century. John Hutchinson is credited with the first assessment of breathing function in 1846 using a device called a spirometer, which allowed measurement of inhaled and exhaled volumes. Respiratory physiology and many of the important measurable variables were established using a series of tubes, balloons, spirometers, glassware and chemical measuring techniques. Respiratory physiology laboratories, even into the 1980s, contained many interesting water-sealed and dry-seal spirometers, dry gas meters, Douglas bags, meteorologic balloons, chart recorders and other devices dragooned into service for pulmonary function and exercise testing.

The onset of the computer era in the late 20th century has revolutionised pulmonary physiology. Technological

advances have made measurement of many pulmonary function and other physiological variables available to many outside the dedicated respiratory physiology laboratory. These advances include the dramatic increase in computer processing power and the ready availability of computers, and miniaturisation made possible by advances in integrated circuit technology. Bulky water-seal (Fig. 1) or dry-rolling-seal spirometers have been replaced by compact pneumotachographs of varying designs (Fig. 2), and gas analysers can now provide continuous and nearly instantaneous results. Complex pulmonary function tests, exercise tests, gas and blood gas analysis and sleep studies are now available with equipment not much larger than desktop computers. The result has been an explosion in the number of devices designed for testing and a

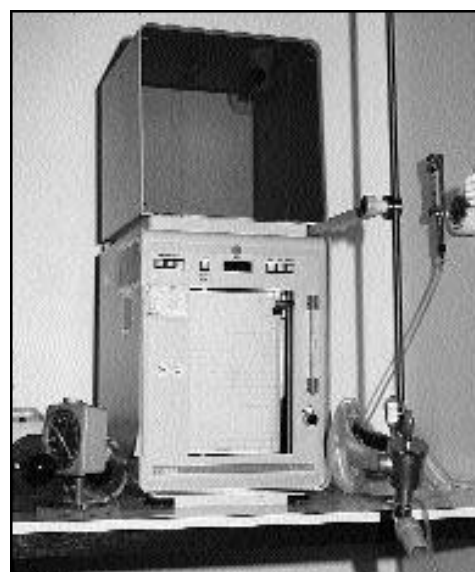


Fig.1. A typical bulky water-sealed spirometer. Spirometry traces were drawn on paper during respiratory efforts and then measured manually using a ruler and calibration traces.

massive increase in the availability of complex physiological measurements. There are both positive and negative aspects to this plethora of information.



Fig. 2. A modern unheated pressure-drop pneumotachograph which requires only attachment to a personal computer loaded with the appropriate software.

ADVANTAGES OF TECHNOLOGICAL ADVANCES

These include advantages for the requesting clinician as well as for the technologist tasked with performing the test. Many of the early pulmonary function testing systems required laborious calibration before each use, often leading to omission of this essential step with resultant loss of accuracy in the measurements made. This was highlighted by Basson and Stewart¹ in 1991, who researched the question of spirometer use in 45 medical practices and found that only 6 regularly calibrated the spirometer. Forced vital capacity was under- or over-recorded by between 6% and 30% in 14 instances.¹ Guidelines published by the American Thoracic Society regarding the performance of spirometry have resulted in most systems now requiring at least daily calibration before use or a warning statement on results that calibration has not been recently performed.²

Automation of many tasks such as valve switching means that more precise timing is possible and the technologist is able to concentrate on the performance of the required

manoeuvre by the subject, rather than on the equipment. This allows better coaching and early correction of errors of performance by the subject. Better interaction between the technologist and the subject without equipment-related distractions should allow for better reproducibility and reliability of efforts. Computer-driven testing protocols ensure that testing is more standardised and many tests have criteria for adequacy of measurement built into them and the system will recommend rejection of data. Correction factors such as BTPS and ATPS are automatically programmed into the calculations ensuring compliance with usual conventions for reporting of results.

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Results are rapidly available and calculations are accurately performed with transcription errors kept to a minimum. Computer-generated standard reference values (provided values appropriate for the population being tested are chosen) are also readily available, improving the reliability of interpretation of the results.

DISADVANTAGES OF TECHNOLOGICAL ADVANCES

Technological improvements are not always beneficial and those related to pulmonary function testing are no exception. Testing

equipment has now become a 'black box' — gas and other samples are taken in and measured and results are produced. Data transparency is reduced as the data entered into calculations are usually not available, the algorithms behind the calculations are sometimes obscure or not well validated and neither the technologist nor the clinician has the capacity to easily adjust obviously incorrect results. The phenomenon of 'garbage in, garbage out' is very prevalent in automated testing systems and requires vigilance on behalf of the clinician to detect this. Report formats are often unwieldy and difficult to reformat. Frequently many variables of dubious relevance are produced and their profusion may divert attention from those that are clinically most important.

A serious drawback to automated systems is the reduced understanding of what is being measured and how actions by the subject or the technologist might influence these. Measurement of gas exchange at rest and during exercise are particularly prone to this type of problem. Averaging and smoothing of data that occurs with many systems can obscure important events. Many advances in respiratory and exercise physiology have been made serendipitously with unusual recordings prompting an exploration of the underlying phenomena. The rigid and proprietary analysis algorithms employed in most modern systems make it impossible to customise or adapt equipment to undertake any tests that are not directly available in the system.

Further disadvantages include the rapid obsolescence of equipment with progress in other areas, often causing otherwise functioning systems to become useless as the ability to interface data input or software with new computer hardware

or operating systems may be lost. Further expense often results from inflexible designs. In times gone by, exercise testing and sleep studies were performed using the same equipment by day and night. Current technology requires separate systems which are mutually incompatible to perform these tests.

THE ROLE OF THE CLINICAL TECHNOLOGIST

As the name suggests, the clinical technologist should be the interface between the subject to be tested, the testing apparatus, and the clinician. The training of a clinical technologist is in performing the various respiratory physiology tests and this requires knowledge of the mechanics of the test, calibration and use of the apparatus used for testing, and most importantly, coaching of the subject in the techniques to be used, supervision of the test, and correction of subject-induced errors in test performance. The attributes of a good clinical technologist, apart from knowledge of the pure technological side of the task, are:

- an ability to handle a wide range of people and empathically explain manoeuvres
- the ability to recognise incorrect results and repeat the test before the subject leaves the testing environment
- a cynical, but insightful, distrust of results produced by physiology testing equipment with the willingness to troubleshoot by repeated calibration and testing until satisfied that the results are as good as can be obtained.

THE ROLE OF RESPIRATORY TECHNOLOGY IN CLINICAL MEDICINE

The formidable array of technologies available and many of the technical considerations might suggest that respiratory physiology and

the technology used for measurement of various values should be kept in the specialist physiology laboratory and not unleashed on the general population. This is probably true for a number of areas, including measurement of subdivisions of lung volumes, diffusing capacity, gas exchange, exercise testing, and sleep studies. However, the improvements in technology outlined above have made spirometers widely available, user-friendly and reasonably priced. There can be no excuse for the spirometer not moving into the practitioner's consulting room alongside items such as the stethoscope and otoscope. Abnormal spirometric values are well recognised as an indicator of morbidity and increased mortality.

Spirometry basically measures air-flow out of fully inflated lungs. Historically, spirograms were recorded by measuring volume and recording this against time.

Modern devices more usually consist of some form of pneumotachograph and record flow against time. Integration of this signal produces volume and so it is possible to produce both volume-time plots and flow-volume curves. The important measurements for clinical and epidemiological practice are those derived from the volume-time curve (Fig. 3) and these are the forced vital capacity (FVC) — the maximum volume of gas exhaled after a maximal inspiration — and the forced expiratory volume in 1 second (FEV_1) — the volume of gas exhaled in the first second of the FVC manoeuvre.

The ratio FEV_1/FVC is of great importance in diagnosis and is usually expressed as a percentage. The expiratory flow-volume curve (Fig. 4) has become increasingly widely used and a number of more complex values can be measured from this. These include the peak expiratory flow rate (PEFR), which should be achieved within 0.1 sec-

onds of starting the expiratory effort, and other values such as the forced expiratory flow between 25% and 75% of FVC ($FEF_{25-75\%}$). These more complex measures do not have much clinical relevance but are important in the more precise research world. The coefficient of variation in measurements such as $FEF_{25-75\%}$ is reasonably large and considerable discretion is required in their use.

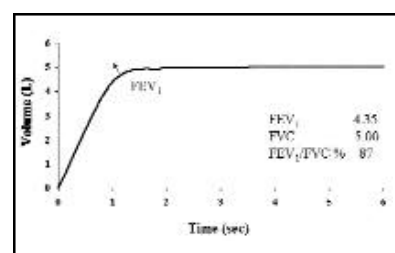


Fig. 3. An example of a normal volume-time plot. FEV_1 is measured where the volume trace crosses the vertical line up from 1 second after onset of exhalation, FVC is measured as the plateau achieved after complete exhalation.

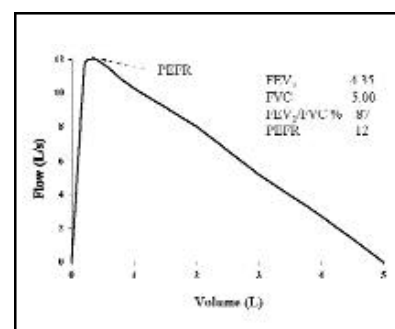


Fig. 4. An example of a normal expiratory flow-volume curve. FVC is the volume exhaled during the expiratory effort but FEV_1 cannot be measured directly from the flow-volume curve and must be obtained from a synchronous volume-time curve.

The values recorded during a forced expiratory manoeuvre depend upon the elastic recoil of lungs and chest cage, and small and large airways function. An important point is that although the initial part of a forced exhalation from maximal inspiration is effort dependent, it becomes much less dependent upon effort

once approximately 20% of the vital capacity has been exhaled. It is this property that makes the FVC and FEV₁ reliable measurements with low coefficients of variation compared with many other measures of pulmonary function. Full inspiratory manoeuvres and maximum expiratory effort are important for ensuring reproducible results.

The South African Thoracic Society Guide for Office Spirometry to be published shortly includes the following as indications for spirometry:

- confirmation of diagnosis of obstructive or restrictive lung disease
- monitoring change in health status in those with chronic respiratory disease or in occupations that are exposed to injurious substances
- grading respiratory impairment for assessing the need for or intensity of treatment, or for medicolegal evaluations, or for preoperative evaluation prior to thoracic or upper abdominal surgery
- screening for lung disease among smokers, those with persistent respiratory symptoms, prior to employment in those with potential for exposure to hazardous substances, or in those regularly exposed to hazardous workplace substances.

PERFORMANCE OF SPIROMETRY IN THE OFFICE SETTING

Spirometers may be of the volume-accumulating or flow-measuring type but should be validated according to minimal performance criteria laid down by the American Thoracic Society.² Important points include accuracy over a range of volumes and flow rates, the ability to produce real-time graphs, computer-driven quality

indicators, ability to print records, and ease of calibration procedure.

The most important factors in ensuring reproducible and accurate results are human. The operator (ideally a clinical technologist or other individual who has undergone appropriate training) must understand the principles of testing and equipment operation and must be able to explain clearly the manoeuvres required of the subject to be tested.

The subject must be seated comfortably and then instructed to inhale fully and then forcibly exhale into the mouthpiece of the apparatus for as long as possible. Repeated explanation, encouragement, and demonstration are helpful as maximum efforts ensure reproducible results. A nose clip may be useful in some instances. Common problems in producing acceptable efforts include leaks at the mouth or nose, protrusion of the tongue into the mouthpiece, coughing, and attempts to breathe in before full exhalation is completed.

A technically acceptable attempt has distinct features on the flow-volume or volume-time curve produced by the apparatus. These include no hesitation at start of exhalation with a rapid rise in flow rate, PEFR reached within the first 15% of FVC (if a flow-volume curve is displayed), and the exhalation must be smooth without coughs, gasps or second breaths. Expiration should last at least 6 seconds or until a plateau in volume or zero flow is reached (this may take up to 15 seconds in individuals with severe airflow obstruction). At least 3 technically acceptable attempts should be recorded. Efforts are deemed reproducible when the values for FVC and FEV₁ on at least 2 attempts are within 100 ml or 5%.

INTERPRETATION OF SPIROMETRY RESULTS

Pulmonary function in health varies with age, stature and gender. There are a number of prediction equations available and it is important that the equations chosen or programmed into the spirometer reporting system are appropriate for the population under investigation. In general we have found that the reference equations produced by the European Community for Coal and Steel (ECCS)³ produce reference values that are acceptable for our population in Cape Town. The question of adjustment for ancestry is controversial with some authors recommending an adjustment of between -10 and -13% for individuals not of European descent.

The interpretation of spirometry results is aimed at establishing the underlying disease process and then assessing severity. The most important value in terms of partitioning the disease process into obstructive or non-obstructive is the FEV₁/FVC ratio. A value of less than 70% is indicative of an obstructive process such as asthma or chronic obstructive pulmonary disease (COPD). Distinction between asthma and COPD may be made by repeating the spirometric testing after administration of a short-acting inhaled beta-2 agonist bronchodilator such as salbutamol. An improvement in FEV₁ of 12% and at least 200 ml is regarded as significant.

A normal FEV₁/FVC ratio with reduced FVC is suggestive of a restrictive ventilatory disorder. Common causes of this include the interstitial lung diseases such as idiopathic interstitial pneumonitis or sarcoidosis, pneumoconiosis, chest cage or vertebral deformity, respiratory muscle weakness, or previous destructive lung disease such as tuberculosis. Severity is

usually graded compared with predicted values and a suggested guide is presented in Table I.

SPIROMETRY IN THE MANAGEMENT OF RESPIRATORY DISEASE

Obstructive lung diseases such as asthma and COPD affect a considerable proportion of the population, between them at least 10% of adults. Cost-effective use of the available treatment options for these conditions is totally dependent upon accurate assessment of the severity of the disease and then ongoing monitoring. International efforts such as the Global Initiative for Asthma (GINA) and Global Initiative for Chronic Obstructive Lung Disease (GOLD), along with guidelines issued by regional thoracic societies, emphasise the role of pulmonary function testing, particularly spirometry, in the assessment and effective management of these conditions. The guidelines of the South African Thoracic Society for the management of chronic asthma,⁴ and for COPD⁵ (recently revised but not yet published), also emphasise the fact that it is impossible to reliably make these diagnoses or to institute effective management in the absence of adequate spirometric testing. Attempting to manage obstructive airways disease with anti-inflammatory and bronchodilatory drugs without spirometry has been likened to trying to manage diabetes without measuring blood glucose or to administer warfarin without monitoring the INR.

Assessment of asthma control historically has often depended upon health care worker or patient evaluation of a single or a limited number of end-points such as PEFR or symptoms. The advances in computer technology and the availability of reliable and reasonably priced portable spirometers have opened new opportunities for remote or

Table I. Guide for grading spirometric abnormalities based on percentage of predicted value

	Normal	Mild	Moderate	Severe
FEV ₁	80%	60 - 79%	41 - 59%	40%
FVC	80%	60 - 79%	51 - 59%	50%

computer-assisted guideline management of obstructive lung disease.⁶ Home spirometry measurements (PEFR or FEV₁) and electronic asthma diary recordings can be downloaded via a modem to a monitoring system. Deviations outside preset parameters will alert a programme co-ordinator who can then contact the patient or the patient's physician about the changes and suggest appropriate guideline-based alterations to maintenance treatment. This type of system has been shown to reduce overall health care expenditure in pilot studies.

CONCLUSION

New technologies in respiratory medicine have opened exciting doors for more effective patient management by making previously complex measurements available in user-friendly and compact equipment. User-friendly, however, does not remove the need for appropriate training in the use of such equipment. Calibration, proper setup, effective patient coaching and ensuring that tests meet applicable standards, are still essential. The cost of acquiring and maintaining equipment, along with the need to purchase and store special gas mixtures for more sophisticated respiratory physiology tests, means that these will remain in the domain of specialised respiratory services and continue to be performed by clinical technologists.

References available on request.

Websites

Global Initiative for Asthma (GINA): <http://www.ginasthma.com>

Global initiative for Chronic Obstructive Lung Disease (GOLD): <http://www.goldcopd.com>

IN A NUTSHELL

Technological advances have allowed complex respiratory physiology measurements to be made outside of dedicated pulmonary function laboratories.

Office spirometry is an essential component of the effective management of respiratory disease, particularly asthma and COPD.

Spirometers for consulting room use need to conform to technical standards recommended by the American Thoracic Society.

Regular calibration of all pulmonary function testing is mandatory.

The most reliable results from pulmonary function tests are obtained when the operator is a qualified clinical technologist or has undergone appropriate training in the tests to be performed.

Reliable spirometry results require maximum inspiratory and expiratory efforts and technically acceptable curves. At least 3 acceptable curves are necessary and at least 2 should have reproducible values.

Reference values that have been demonstrated to be applicable to the population under study should be used. The ECCS reference equations are generally appropriate for South African use although an allowance may need to be made for individuals of non-European ancestry.

Complex pulmonary function and exercise tests should be reserved for dedicated respiratory physiology laboratories as specialised testing gases, more complex equipment and appropriately trained and qualified staff are essential.